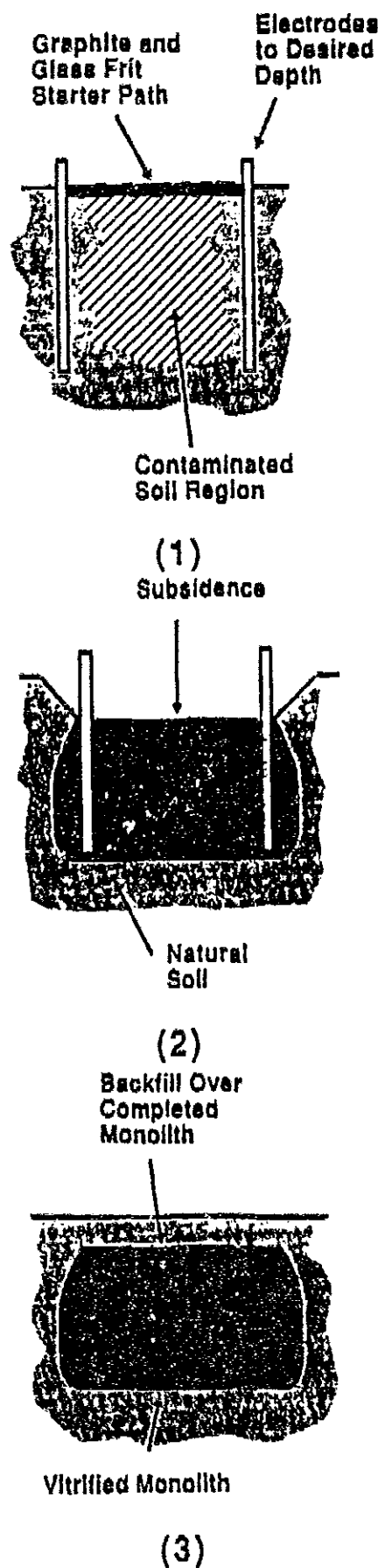


Fig. 1: ISV Processing Stages



Source: Geosafe Corp.

process mixtures of these waste types simultaneously is a significant advantage compared to other remediation technologies.

Although ISV is broadly applicable, there are limits to its uses. Most significant is the rate of groundwater recharge if the process is to be applied in the saturated zone. Because ISV must remove water from the soil before it will heat to the melting point, the rate of recharge is significant. Applications involving hydraulic conductivity at levels exceeding 10^{-4} cm/sec are considered marginal from an energy consumption standpoint; that is, the use of barrier walls, well points or some other means to limit recharge would be cost-effective compared to removing water by electrical heating.

ISV off-gas processing equipment also has limits relative to the amount of heat load and the volume of gases it can process. These limits are associated with the concentration of organics and other gas-generating materials that may be treated per unit time by the equipment. A rule-of-thumb organic concentration limit of 5 to 10 weight percent is used for initial application screening. Specific sites must be considered in detail prior to application.

Metals concentration limits are typically high relative to the amount of metals found in most hazardous waste applications. General metals concentrations in the 5 to 16 weight percent range are considered processable without special adaptations. Continuous metal contact (for example, pipeline or re-bar) up to 95 percent of the distance between opposed electrodes also is acceptable. With these capabilities, the process may be used to treat contaminated drums and other metal components.

Another metals consideration is related to the solubility of the metal in the melt and residual product. The reducing environment of the typical ISV melt will produce pure metal beyond the limits of metal solubility in the melt. Depending on the volatility of the metal, it may either evolve from the melt or stay as a metallic inclusion within it. Mercury is a notable example of a metal with low solubility and high vapor pressure at the ISV melt temperatures. Essentially all mercury is removed from the treatment zone during processing and collected in the off-gas treatment system. At the other extreme, high concentrations of iron may pool near the bottom of a melt and be encapsulated by the glass at that location.

ISV also can accommodate a significant quantity of rubble, debris or other inclusions within the treatment zone. Concrete, for example, will dehydrate, turn to powder and become part of the melt;

the typical constituents of concrete are good glass-forming materials. Each application needs to be addressed in detail to determine whether, and under what conditions, it may be suitable for ISV processing.

Typical remediation projects using ISV treatment involve:

- Site characterization;
- Treatability/pilot testing;
- Remedial design;
- Permitting/compliance analysis and documentation;
- Site preparation;
- Equipment mobilization;
- Onsite vitrification operations;
- Equipment demobilization;
- Site restoration; and
- Delineating or long-term monitoring.

The cost of these activities is dependent on specific conditions at the site, and overall project criteria and objectives.

Costs. Treatability/pilot testing is used to:

- Demonstrate that the technology is applicable to the specific soil/waste combination at the site;
- Produce contaminant-related performance data necessary to support permitting activities;
- Produce operation-related performance data necessary to support cost estimates and quotations; and
- Produce samples of residual product for use in community relations efforts.

Treatability testing involves the performance of various physical and chemical tests on actual contaminated materials from the site, followed by engineering-scale ISV melt testing on the materials. The cost of treatability testing is in the range of \$35,000 to \$40,000. Unusual analytical requirements, such as those posed by dioxin analyses, may increase the costs. Treatability testing usually can be completed within eight to 10 weeks after project initiation.

The cost of equipment mobilization and demobilization depends on transport distance to and from the site. The combined total of these costs may be estimated at \$50,000 plus \$50 per transport mile. Typical total mobilization/demobilization costs fall in the range of \$100,000 to \$200,000.

The onsite service cost of ISV processing usually is in the range of \$250 to \$350 per ton of material processed. This includes all elements of direct and indirect cost, such as labor, materials, energy, equipment amortization, and contractor overhead and profit. The most significant variables affecting the cost include cost of electrical power, amount of water to be removed during processing, and analytical chemistry requirements associated with process control and per-

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Residual product. Shown above is 10 tons of soil vitrified in the pilot scale test. BATTELLE MEMORIAL INSTITUTE

percent to 40 percent. Vitrification is the only means available to eliminate such void volume. In addition, further volume reduction may be achieved through decomposition of solids into gaseous products (for example, limestone converts to calcium oxide and carbon dioxide). Volume reduction results in a subsidence of the melt surface below the original starting grade. At the completion of processing, clean backfill is placed over the residual monolith to depths desired for subsequent land-use needs.

The ISV residual product from soil applications is typically about 10 times stronger than unreinforced concrete, both in tension (4,000 psi to 8,000 psi) and compression (30,000 psi to 45,000 psi). It is not affected by either wet/dry or freeze/thaw cycling.

Individual ISV process settings may possess a mass of 1,000 tons. Adjacent settings fuse together into a single monolith; thus the residual product presents a minimum of surface area to the surrounding environment. Even when reduced to fine particle sizes, the ISV residual product easily passes EPA's EP toxicity and TCLP testing criteria. EPA also has found the ISV residual to have acceptable levels of biotoxicity relative to near-surface life forms.

As with other monolithic waste forms,

life expectancy of the ISV residual product is difficult to estimate based on comparatively short-term leach tests. However, the ISV residual has the advantage of being physically and chemically analogous to natural obsidian, a glass and crystalline product of volcanic origin that has been studied extensively for its age and weathering characteristics. Scientists believe that the mean age of natural obsidian is 18 million years². During hydration, obsidian forms a protective rind that limits further corrosion. Unless there are abusive physical processes degrading the ISV residual product within the environment, the ISV product also should withstand environmental exposure for geologic time periods (that is, thousands to millions of years).

Equipment. The ISV process allows contaminated materials to be treated in their existing location. The materials also may be consolidated and staged for treatment at a desired processing location. The ISV equipment (Fig. 3) is mounted on over-the-road trailers so that it is mobile. The equipment is designed for quick interconnection at the site; typical readiness time is about one week after arrival.

The primary component of the equipment system is the off-gas collection and treatment system. A 55-foot dia-

meter off-gas collection hood directs any materials evolving from the treatment zone to the off-gas treatment system. The system cleans off gases with quenching, venturi scrubbing, mist elimination, humidity control, filtration and carbon adsorption unit processes.

The quenching and scrubbing solution is cooled by a self-contained glycol system, eliminating a continuous supply of onsite water. Periodically, any contaminants collected in the scrubber solution, filters and/or carbon beds may be recycled to a subsequent ISV setting. Only secondary waste at the end of the last setting at the site requires further treatment or disposal.

Because most of the gases that evolve during ISV are innocuous, off-gas cleanup is easily accomplished. Also, because ISV does not involve combustion of any fuels to attain high processing temperatures, there is no need to process the large volume of fuel combustion products present during most incineration operations. A diesel-powered, backup off-gas treatment system is employed to allow continued processing of off-gases in the event of power failure.

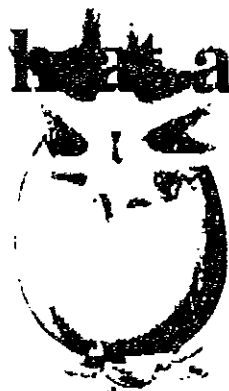
The ISV equipment system also includes an electrical power conditioning capability. Electric power is typically taken from a utility-provided service at either 12.5 kilovolts or 13.8 kilovolts. The AC power is converted to 2-phase and transformed to 4,000 volts for initial processing.

Voltage is further reduced periodically during an ISV setting to offset the increased conductivity provided by the growing melt. Typical soil applications require 0.35 kilowatt hours to 0.4 kilowatt hours per pound of material treated. Since the large-scale ISV equipment processes a nominal 10,000 pounds per hour, an electrical service approaching 4,000 kilowatts is necessary. That is about as much power as is consumed by an average-size hotel in a major city. Such electrical service is readily available through public utilities; the needed power may also be diesel-generated in remote locations.

The limits. The ISV process has been under development and demonstration by Battelle Memorial Institute since 1980. The majority of work performed has been for the U.S. Department of Energy (DOE); however, significant work also has been done for various private and other government sponsors. The ISV process was developed and demonstrated through large-scale projects, and wastes treated have included a variety of hazardous chemical, radioactive and mixed (hazardous chemical and radioactive) wastes. The ability of ISV to

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In-situ vitrification: heat and immobilization are combined for soil remediation



By James Hansen
and Vincent FitzPatrick

SARA mandates that EPA give priority to treatment technologies that offer permanent remedies; are capable of reducing the toxicity, mobility or volume of hazardous materials; and that can be performed onsite and *in situ*. These criteria have proven to be particularly challenging in the difficult area of remediating contaminated soils, sludges, sediments and process tailings. *In Situ Vitrification* (ISV) is a unique new technology that potentially can satisfy the congressional mandate for these difficult wastes.

How ISV works. The ISV process involves *in situ* electro melting of contaminated solids at high temperatures, typically in the range of 1,600° C to 2,000° C. Fig. 1 illustrates the process cycle, and Fig. 2 presents typical process conditions.

Four electrodes are placed to the desired treatment depth. Because soil typically does not have sufficient electrical conductivity to allow process initiation, a mixture of graphite and glass frit is placed on the surface between the electrodes to serve as an initial conductive (starter) path. As electric potential is applied between the electrodes, current flows through the starter path, heating it and the adjacent soil to temperatures above 1,600° C, which is well above typical soil fusion temperatures.

Upon melting, soil becomes electrically conductive; thus the molten mass becomes the primary conductor and heat-transfer medium allowing the process to continue beyond startup. Joule heating of the molten mass occurs as the electric power is passed between the two pairs of electrodes. Heating of the mass is aided by convection currents within the melt. Heat is transferred to the adjacent soil by conduction from the melt.

As the high-temperature melt moves slowly downward and outward through the contaminated solids (4 to 6 tons per hour, yielding an advance rate of 1 inch to 2 inches per hour), a steep thermal gradient (150° C to 250° C per inch) precedes the melt. At appropriate temperature regimes within this gradient, or within the melt itself, the solids and contaminants undergo physical changes and decomposition reactions.

The possible dispositions of particular contaminants resulting from ISV processing include chemical or thermal destruction, removal from the treatment volume to the off-gas treatment system, and chemical or physical incorporation within the residual product.

Application considerations. Many site- and application-specific variables affect the disposition of specific contaminants. The primary variables include physical and chemical properties of contaminants, melt chemistry, melt temperature, contaminant dwell time in the treatment zone, adjacent soil properties, soil moisture content, and extent of overmelting (soil melted beyond the limit of contamination). Because of the many site-specific variables involved, it is necessary to consider each remediation project individually.

Performance. The ISV testing program has indicated that certain classes of contaminants may be expected to undergo basic types of response and ultimate disposition during treatment. Hazardous compounds undergo the phenomenon of pyrolysis (thermally induced decomposition of compounds into their elements, usually in the absence of oxygen). For example, chlorinated organics decompose to carbon, hydrogen and chlorine, and nitrates break down into nitrogen and oxygen.

The ISV process produces an obsidian-like re-

In addition to pyrolysis products, it also is possible that limited quantities of highly volatile materials may evolve from the treatment volume during processing. All evolved materials are captured in a collection hood and subjected to off-gas treatment processes to ensure all emissions are within regulatory limits.

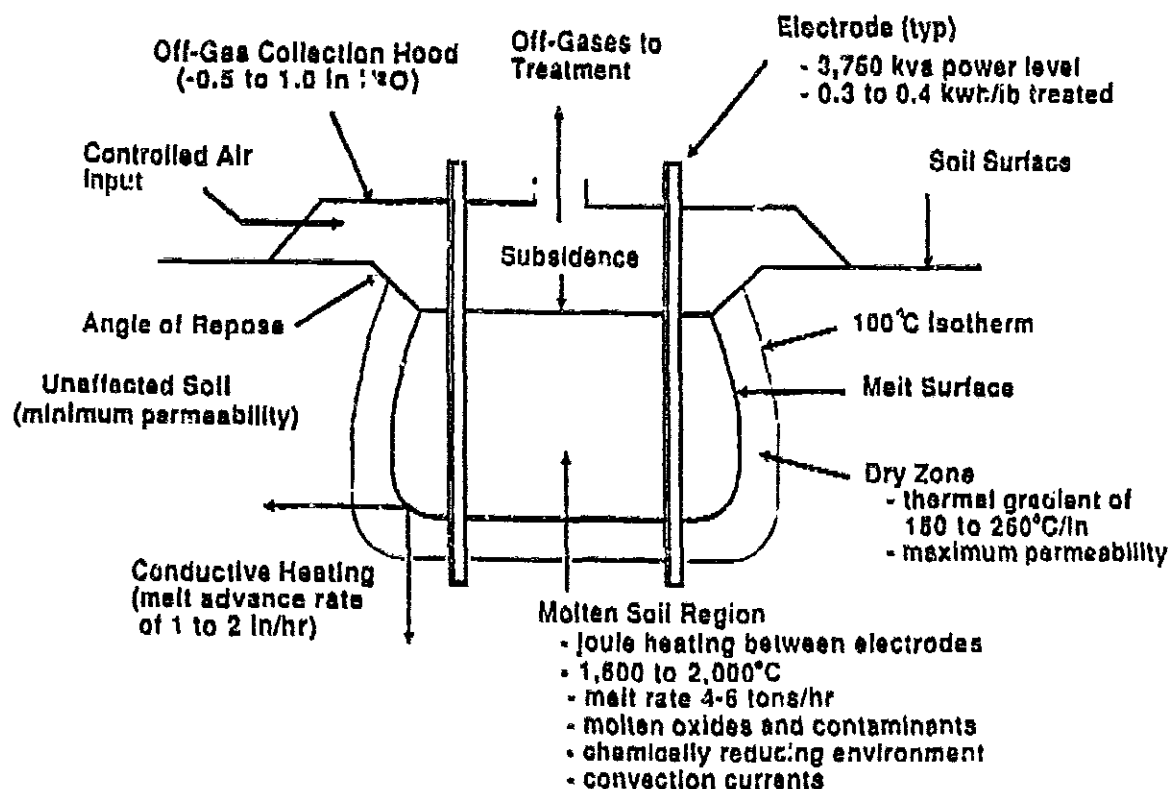
Solid media also decompose during processing. For example, the inorganic portion of soils, which consists of complex mineral compounds, typically breaks down into major oxide groups, such as silica and alumina. The ISV melt consists primarily of these major oxides, which, upon cooling, form a glass and crystalline product with outstanding environmental exposure properties.

Inorganic elements that do not evolve from the melt during processing become part of this residual product through physical or chemical incorporation. Tables 1 and 2 present typical results from the ISV development and testing program, indicating performance on various types of contaminants. Table 1 presents organic destruction and removal results, and Table 2 presents heavy metal retention, removal and leach testing results.

Volume reduction. ISV processing eliminates the void volume present in particulate materials, such as soils, resulting in typical volume reductions of 20



Fig. 2: Typical ISV Process Conditions



Source: Geosafe Corp.

mit compliance. Using information on these and other pertinent variables, application-specific cost estimates may be developed.

Project expansion. Battelle continues to extend the technology to various radioactive, hazardous chemical and mixed waste applications of interest to DOE. DOE granted Battelle specific rights to the technology in exchange for its commercialization. To accomplish commercialization, Battelle established Geosafe Corp. (Kirkland, Wash.) as the exclusive sublicensee to provide onsite ISV remediation services.

ISV technology is a participant in EPA's SITE program. A specific site has not yet been selected for the ISV demonstration, which EPA will evaluate. Care is being given to selection of a site that will evaluate as much of the technology's applicability to potential Superfund sites as possible from a single project.

ISV currently is being considered for use at several Superfund and RCRA Corrective Action sites within the United States. EPA has selected the process for remediation of one Superfund Removal, Program site and two Remedial Program sites. These sites contain contaminants such as PCBs, dioxin, pesticides, mercury, and a large number of other organics and inorganics at varying concentrations. In addition, it is expected that the ISV technology will be demonstrated on a large scale at one private site (PCBs), one Superfund site (radium and a variety of organics), and two DOE sites during 1990. Two addi-

TABLE 1

Typical Organic Destruction/Removal Results

Contaminant	Percent Destruction	Percent Removal	Total
MEK	>99	>99.9	>99.999
Styrene	>90	>99.9	>99.99
PCBs	>99	>99.9	>99.999
DDT, DDE, DDD	>99	>99.9	>99.999
DDT, Thionex	99.9-99.99	>99.9	>99.9999
Heptachlor	99-99.9	>99.9	>99.99
Aldrin	>97	>99.9	>99.99
PCBs	99.9-99.99	>99.9	>99.9999
PCBs	99.9-99.99	>99.9	>99.9999

This is the percent removed, from the off-gas, of the amount remaining after the percent destroyed; thus the percentages are additive for total DRE.

Source: Geosafe Corp.

TABLE 2

Typical Inorganic Removal/Retention/Leach Results

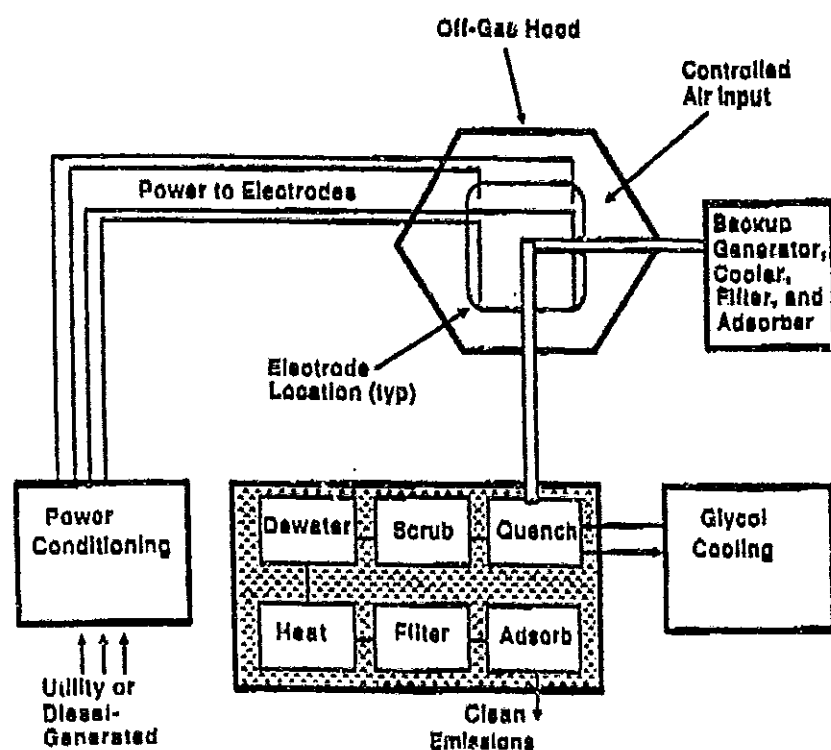
Contaminant	Percent Retention	Percent Removal	Total Ret/Rem	Initial Concns	Final Concns
Pb	90-99	99.9	99.99	5,550 ppm	55-63 ppb
As	70-95	99.9	99.99	49,875 ppm	0.7 ppm
Cd	87-78	99.9	99.99	52 ppm	0.5 ppm
Hg	90	97-99	97	5,360 ppm	Non-Detect
Ba	99.9	99.9	99.9999	185 ppm	140 ppb
Cr	99.9	99.9	99.9999	290 ppm	20 ppb
Ni	99.9	99.9	99.9999	47 ppm	Non-Detect
Ra	99.9	99.9	99.9999	NA	NA
U, Th, Pu	99.99	99.9	99.99999	NA	NA

This is the percent removed, from the off-gas, of the amount not retained; thus, the percentages are additive for total retention and removal.

Source: Geosafe Corp.

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Fig. 3: ISV Equipment Schematic



Source: Geosafe Corp.

tional DOE demonstrations are in the planning stage. ▼

James Hansen is director of marketing and sales at Geosafe Corp. (Kirkland, Wash.). He served as manager of ISV project development and commercialization at the Richland, Wash., laboratory of Battelle Memorial Institute (Columbus, Ohio) for four years prior to the formation of Geosafe. Vincent FitzPatrick is Geosafe's director of engineering, technology and field operations. He was Battelle's manager of ISV programs for the six years prior to the formation of Geosafe. ▼

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TABLE 1. Typical Organic Destruction/Removal Efficiency

<u>Contaminant</u>	<u>Concentration (ppb)</u>	<u>Percent Destruction</u>	<u>Percent Removal (1)</u>
<u>Organic Pesticides:</u>			
4,4' DDD, DDE, DDT	21-240,000	99.9 - 99.99	>99.9
Aldrin	113	>97	>99.9
Chlordane	535,000	99.95	>99.9
Dieldrin	24,000	98-99.9	>99.9
Heptachlor	61	98.7	>99.9
<u>Volatiles:</u>			
Fuel Oil	230-11,000	>99	>99.9
MEK	6,000 (2)	>99	>99.9
Toluene	203,000	99.996	>99.9
Trichloroethane	106,000	99.995	>99.9
Xylenes	3,533,000	99.998	>99.9
<u>Semi-Volatiles:</u>			
Pentachlorophenol	>4,000,000	99.995	>99.9
<u>Non-Volatiles:</u>			
Glycol	8,000 (3)	>98	>99.9
LCBs	19,400,000	99.9 - 99.99	>99.9
Dioxins	>47,000	99.9 - 99.99	>99.9
Furans	>9,400	99.9 - 99.99	>99.9

(1) This is the percent removed, from the off-gas, of the amount destroyed; thus the percentages are additive for total DRE.

(2) 98% MEK in container, yielding 6,000 ppm in layer of container

(3) 50% ethylene glycol in container, yielding 8,000 ppm in layer

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